APPLICATION FOCUSED SCHLIEREN TO NOZZLE EJECTOR FLOWFIELDS

L. Kerry Mitchell, Michael K. Ponton, John M. Seiner, James C. Manning
NASA Langley Research Center
Hampton, Virginia

and

Bernard J. Jansen and Nicholas T. Lagen
Lockheed Engineering and Sciences Company
Hampton, Virginia

S15-07

RESEARCH OBJECTIVE

Motivation: Eddy Mach wave emmission reduction via enhanced mixing
- Ejector shroud
- Contour of mixer exit

Experiment Objective: Visualize mixing performance on inside of ejector

The motivation of the testing was to reduce noise generated by eddy Mach wave emmission via enhanced mixing in the jet plume. This was to be accomplished through the use of an ejector shroud, which would bring in cooler ambient fluid to mix with the hotter jet flow. In addition, the contour of the mixer, with its chutes and lobes, would accentuate the merging of the outer and inner flows. The objective of the focused schlieren work was to characterize the mixing performance inside of the ejector. Using flow visualization allowed this to be accomplished in a non-intrusive manner.

INTRODUCTION TO FOCUSING SCHLIEREN

Figures of Merit:

DU = depth of unsharp focus, to be minimized

ε = angular resolution (~ 1 / sensitivity), to be minimized

Design considerations:

DU requires large D, ε requires small D

Tunnel walls impose constraints on size, mounting

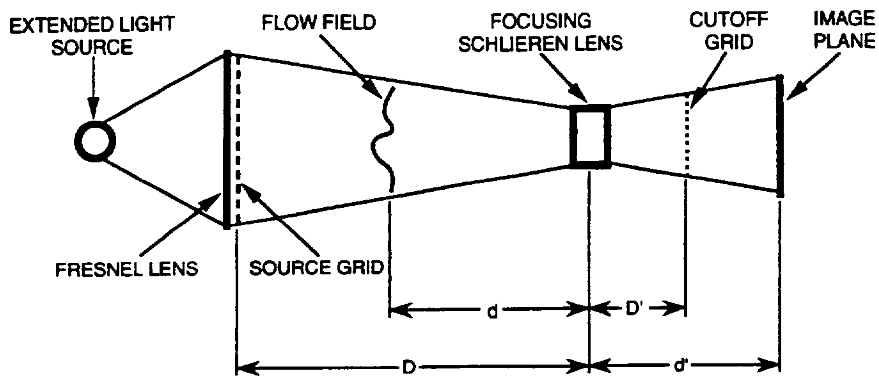
Compromise:

DU = 1.3"

ε = 16 arc-sec

Focusing schlieren was utilized in this work because of its advantages over conventional schlieren. Conventional schlieren requires the use of high quality optical windows. These windows, when subject to aerodynamic stresses on a wind tunnel model, may adversely affect image quality. In addition, with conventional schlieren, the image is integrated over the optical path. With focusing schlieren, it is possible to focus on specific planes in the flowfield. The figures of merit for focusing schlieren are the depth of unsharp focus, that is, the distance over which features become fuzzy; and the angular resolution, which is inversely proportional to the sensitivity of the system. Both of these are to be minimized, which leads to a tradeoff. In this installation, the wind tunnel walls provided additional constraints, as the source and collecting optics were placed outside of the tunnel. As a result, the depth of unsharp focus was 1.3 inches and the angular resolution was 16 arc-seconds.

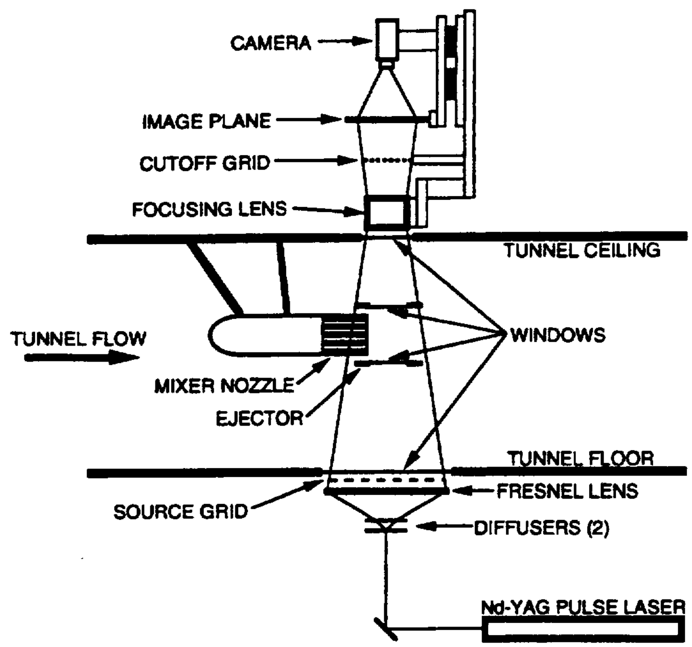
LARGE-FIELD FOCUSING SCHLIEREN APPARATUS



NASA Facility	Lewis	Langley
D (in)	115	88.5
d (in)	50	34.3
D' (in)	27.2	29.3
d' (in)	39.3	61.5
DU (in)	1.31	0.90
ε_{min} (arc-sec)	15.8	19.1

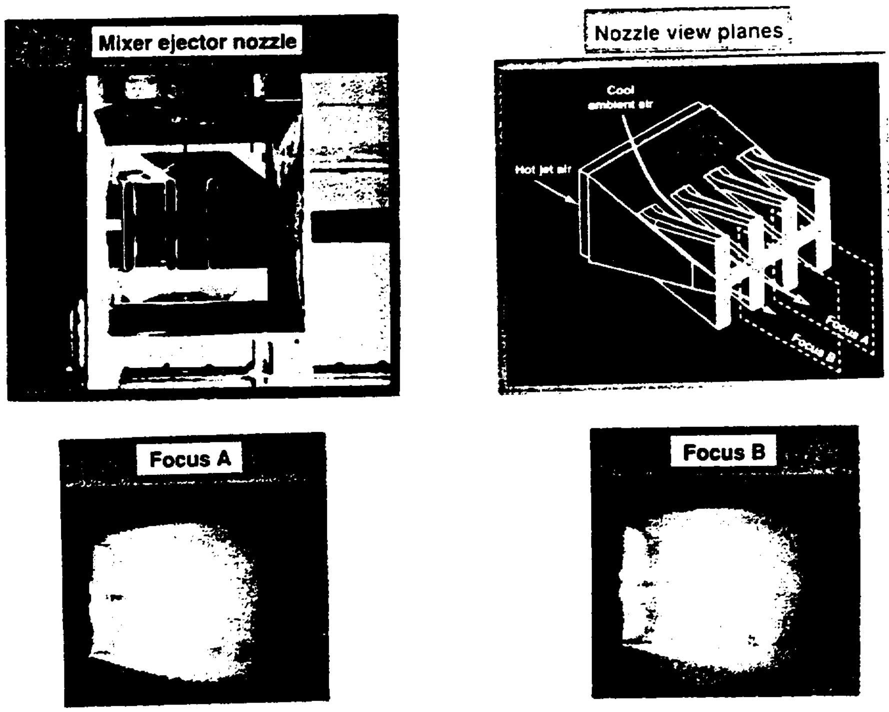
Schematically, a large-field focusing schlieren apparatus consists of source, collecting, and imaging optics. The source optics were comprised of an extended light source (e.g., laser), which was diffused into a fresnel lens. After the lens, the light passed through a source grid, which served to break the light into several slit sources. These sources passed through the flowfield, where they were diffracted by the density gradients in the flow, and were collected by the cutoff grid, the photographic negative of the source grid. This had an analogous function to the knife edge in a conventional schlieren system. Finally, the image was produced on the image plane which was in turn either photographed or videotaped. It was the movement of the image plane which allowed the system to focus on different planes in the flowfield.

SHARP FOCUS SCHLIEREN APPARATUS
NASA LEWIS 9 X 15 WIND TUNNEL



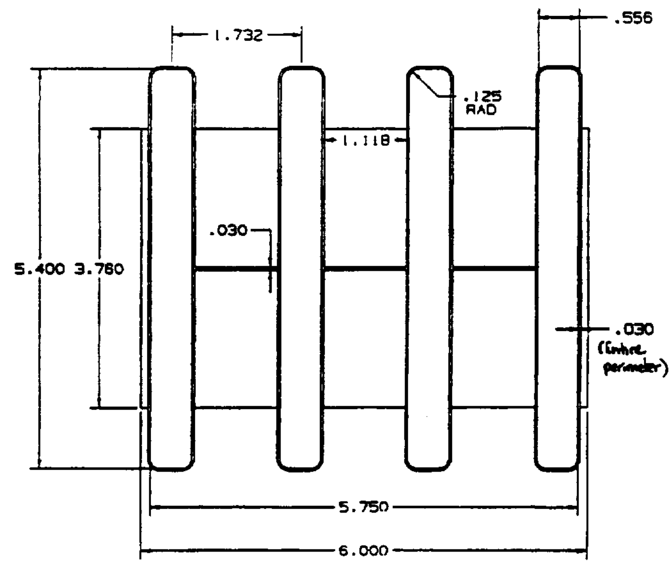
For the present work, the system was installed with the optical axis vertical in the Lewis 9x15 Low Speed Acoustic Wind Tunnel. The light source was a Nd-YAG pulsed laser, frequency doubled to a 532 nm (green) line. The beam left the laser nominally horizontal and was folded to vertical for passage through the tunnel. Two diffusers were used to spread the beam so that it would fill the fresnel lens and source grid. The diffusers, source grid and fresnel lens were mounted underneath, and isolated from, the tunnel floor. The light intersected the ejector flowfield and was collected by optics mounted above the tunnel ceiling. The collecting lens, cutoff grid, and imaging optics were all mounted on a vertical support, isolated from the tunnel A 35 mm still camera and a video camera were used to record images from the image plane. The image plane and cameras were mounted on a vertical traverse, allowing remote selection of focusing planes. The installation of the source and receiving optics was such that the system was not subject to tunnel vibrations. Because of the focusing nature of the schlieren, imperfections and slight motions of the windows in the tunnel walls did not affect the image quality.

HSR NOZZLE STUDIED WITH SHARP FOCUS SCHLIEREN

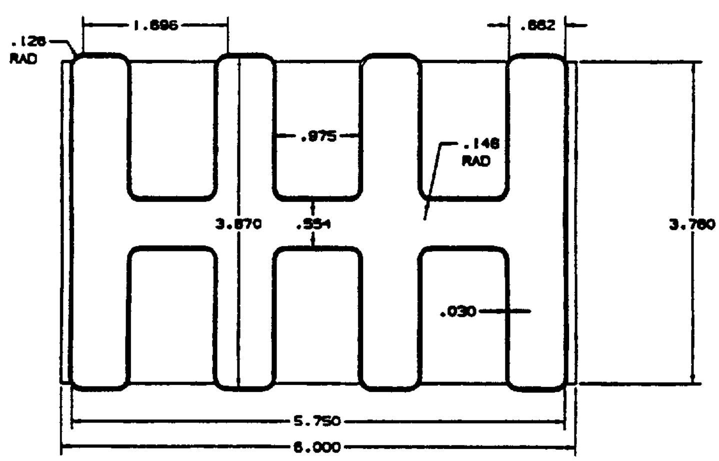


This figure illustrates the nozzle and representative images obtained with the focus schlieren. The mixer nozzle is shown installed in the Lewis 9 x 15 Foot Low Speed Aeroacoustic Wind Tunnel. Also shown is a schematic of the mixer, indicating two planes of focus. Plane A is through a chute at the center of the mixer and plane B is toward one end. Representative views at each of the focus planes are shown. Differences in the detailed structure of the plume can be seen between the central and outer views.

Right End View at Mixer Exit



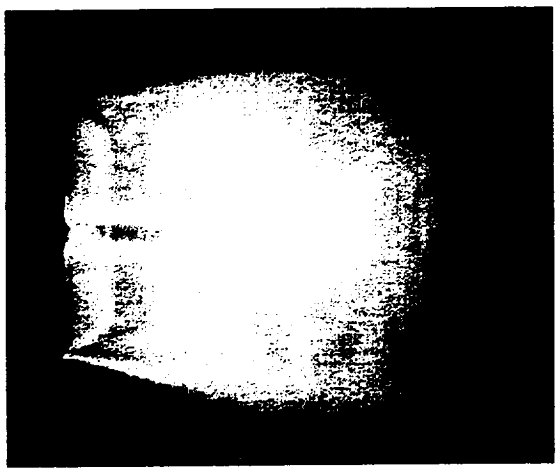
Right End View at Mixer Exit



This figure shows the two mixers tested. The upper was identified as the "axial" mixer, and is essentially 4 high aspect ratio rectangular jets. The central portion between lobes was to be sealed, but video analysis revealed that this seam leaked. The lower mixed was the "vortical" mixer, in which the four lobes were joined by a central channel almost as wide as a lobe. The height of the lobes was adjusted so that both mixers had the same exit area.

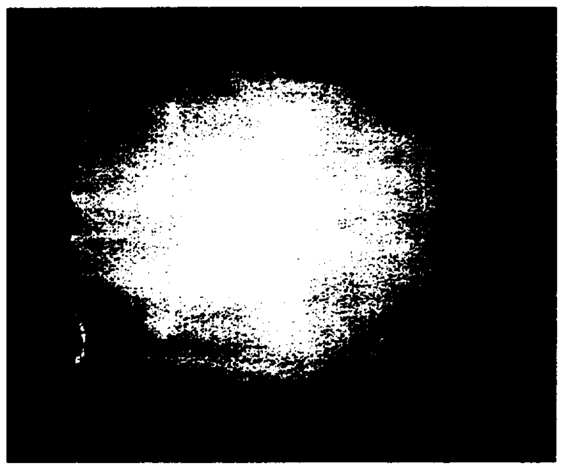
AVERAGED DIGITIZED VIDEO RECORD

POSITION = 3.41"



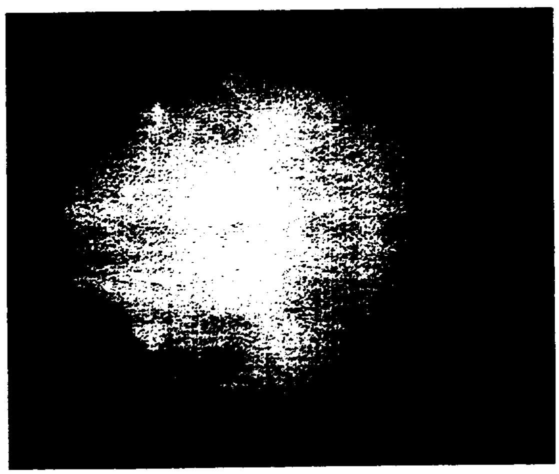
An averaged video record is shown, for the vortical mixer operating without the ejector shroud. Ten video frames were averaged over 1/3 second. The nozzle was operating in an underexpanded condition, at a nozzle pressure ratio of 4.0 and a total temperature of 1500F. The focal plane was at the center of the nozzle, and diamond shocks from the central channel of the mixer are clearly visible.

AVERAGED DIGITIZED VIDEO RECORD
POSITION = 3.41"



In this record, the mixer was operating with the ejector, at a nozzle pressure ratio of 3.5 and a temperature of 1275F, the nozzle's design point. The focal plane was again at the center, and weak diamond shocks are visible. The weak shock structures were validation of the shock-free design of the mixer. Also present were shocks at the inlet of the ejector, indicators of performance degradations.

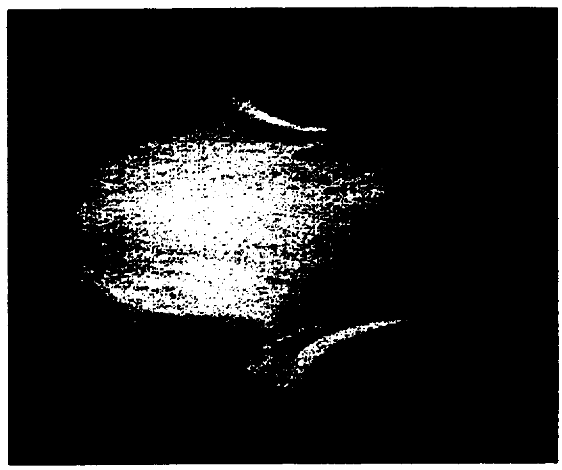
AVERAGED DIGITIZED VIDEO RECORD
POSITION = 5.95"



This record was taken at a focal position through an outer lobe, a distance of 1.5 "depth of unsharp focus" from the center. The operating conditions were the same as the previous figure. The difference are seen in the shock structures; the central diamond shock is no longer visible due to not being in the region of unsharp focus.

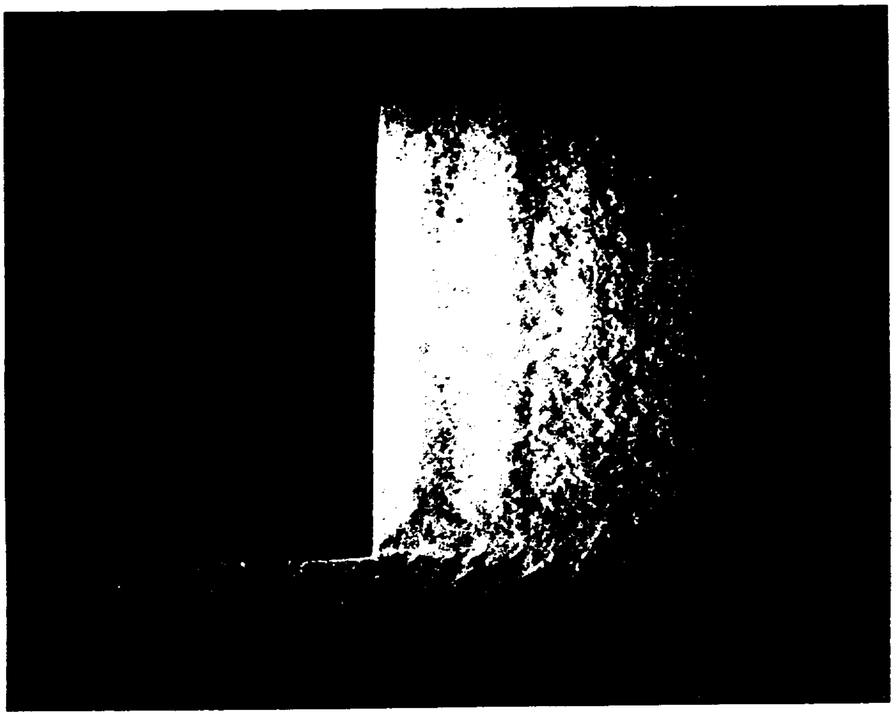
DIGITIZED VIDEO RECORD SHOWING STREAKS CAUSED BY INTERNAL NOZZLE LEAK

(FOCUSED AT THE EJECTOR WINDOW)



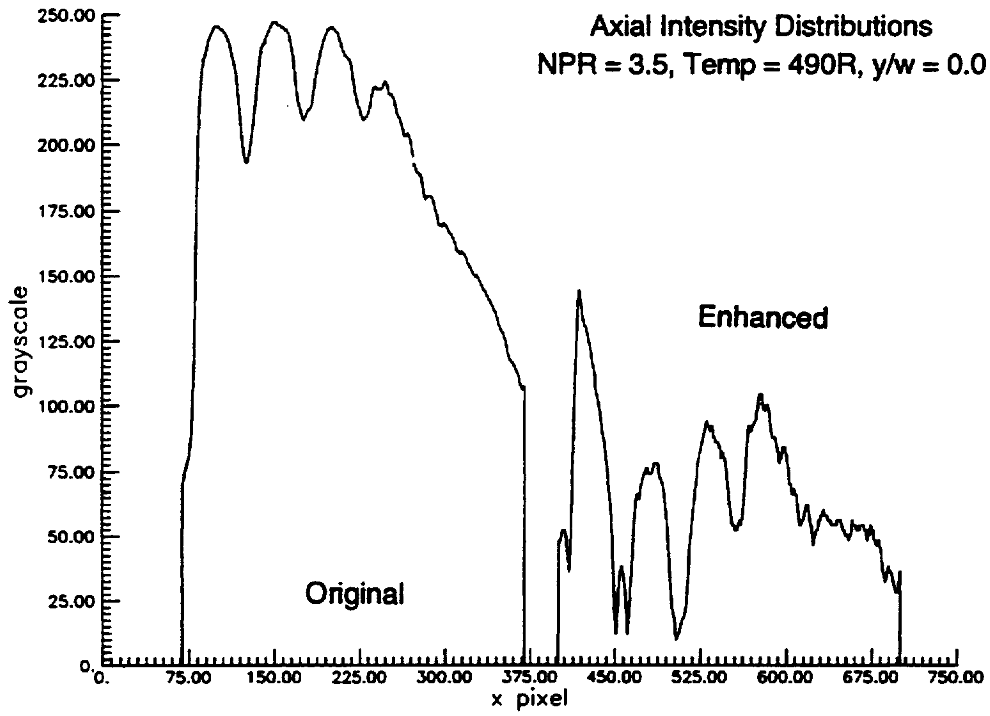
In the previous record, background streaks were apparent. These were due to sealant from the mixer leaking onto the ejector windows. By focusing on the window, these streaks became very clear. As the focus moved to the center, the streaks were essentially unnoticed.

35mm PHOTOGRAPH SHOWING MACH WAVE EMISSION



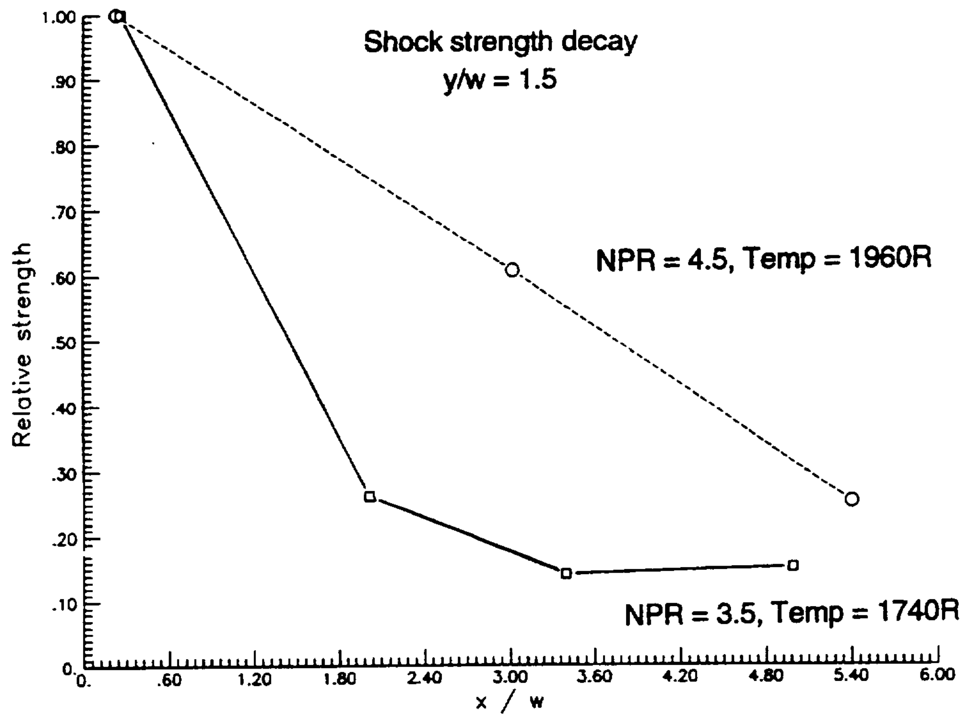
This record shows the axial mixer, operating underexpanded at a nozzle pressure ratio of 4.0 and a temperature of 1500F. Instead of averaging video frames, this still was taken with a 6 ns exposure on a 35 mm camera. This nearly instantaneous snapshot of the free jet shows clearly the eddy Mach wave emission from the shear layer, and the shock cell structures in the plume.

IMAGE PROCESSED SHARP-FOCUS SCHLIEREN
Pratt & Whitney Axial Mixer, no ejector



By utilizing a frame grabber and a computer in conjunction with the video taping of the schlieren, the images can be digitized and quantitative information can be obtained. For an averaged record of the axial mixer, horizontal slices of brightness were plotted. This was for a nozzle pressure ratio of 3.5 and ambient temperature. When the brightness through the center of the plume was plotted, peaks and valleys were observed that corresponded to the shock system immediately downstream of the exit. This distribution was enhanced by removing the effect of background illumination and increasing the contrast. The peaks were then correlated to shock strength and the distance between peaks to the shock cell length.

IMAGE PROCESSED SHARP-FOCUS SCHLIEREN
Pratt & Whitney Axial Mixer, no ejector



Upon digitizing a video record and plotting the brightness against downstream location, relative information about the shock systems were obtained. In this figure, the decay in relative strength is plotted for the axial mixer operating close to design and off design. (For reference, the first shock had strength 1.0.) In the present work, this was used more as an indicator of trends and proof of concept then as a scientific study of shock decay.

Focusing schlieren systems are viable for wind tunnel applications, as long as the constraints imposed by the tunnel are accommodated, and care is taken with the setup. Focusing schlieren systems have advantages over conventional schlieren in that: they can focus on planes in the flowfield, high-quality optical windows are not required, and images can be enhanced with appropriate usage of image processing tools. For mixer/ejector studies, focusing schlieren systems allow non-intrusive investigation of ejector flowfields, global visualization of shock cells and other structures, and quasi-quantitative characterizing of mixing performance.

CONCLUSIONS

Focusing schlieren systems are viable for wind tunnel applications:

- Design constraints imposed by tunnel
- Setup difficult, not impossible

Merits of focusing schlieren systems:

- Planes of the flowfield can be visualized
- Schlieren-quality model windows and optics can be avoided
- Acquisition of no-flow data can assist in image enhancement

Focusing schlieren systems can be useful in mixer/ejector studies:

- Non-intrusive nature allows investigation of ejector flowfields
- Global visualization of structures
- Quasi-quantitative mixing metrics

Session IV

Analytical Aeroacoustics I